How does the retina anticipate the motion of complex shapes ?

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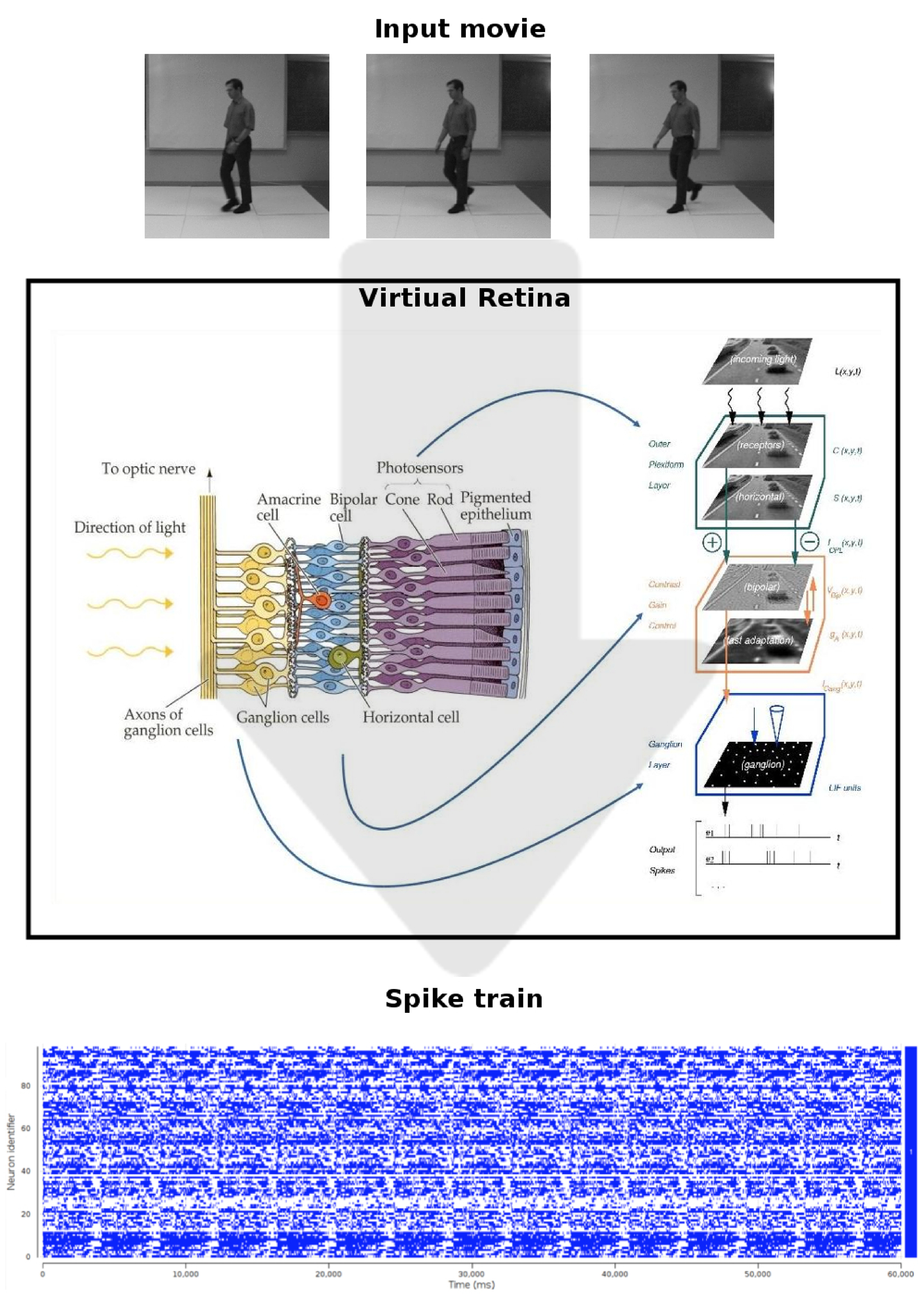
Introduction

- The visual system uses motion anticipation to compensate the delays in retino-cortical transmission.
- Neurobiologists first believed that anticipation only happened in the visual cortex, but recent studies have shown that it starts in the retina.
- Berry & al. (1999) [1] and later Chen & al. (2013) [2] emphasized the role of gain control mechanisms in retinal anticipation.
- Chen's model accounts for two supplementary motion features: alert response to the appearance and to the motion onset of a bar.
- These models simulate independent RGCs whereas these cells are indirectly connected in the retina.
- We want to understand how these mechanisms act on the anticipation of more complex shapes motion
- For this we have developed a retina simulator, PRANAS (https://pranas.inria.fr/) emulating the retina spike response to a visual scene.

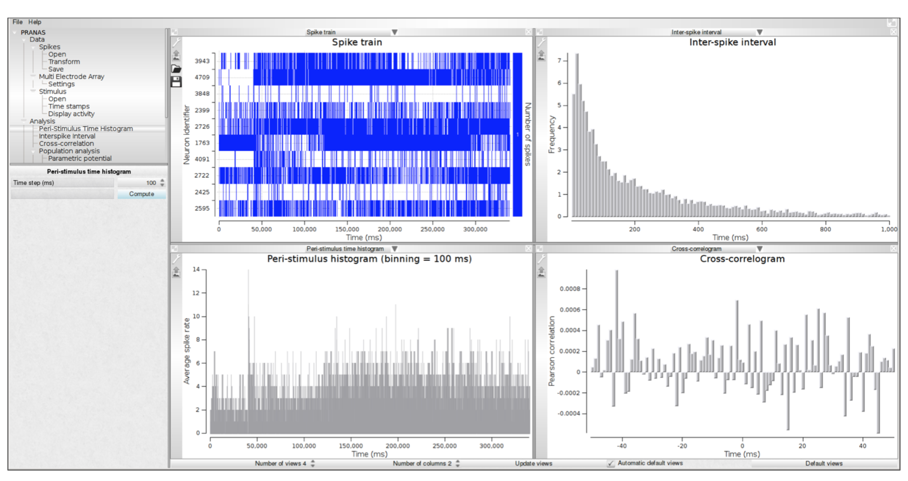
I) Retina Simulator

Virtual Retina [4] is a software able to convert a movie into spike trains similar to those transmitted by the retina to the brain. It uses a three-processing-stage model mimicking photoreceptors, bipolar cells and ganglion cells. It is now embedded in PRANAS.



II) The PRANAS Software

PRANAS also provides tools to analyze the statistics of the population spike response to a general visual scene.



Acknowledgement

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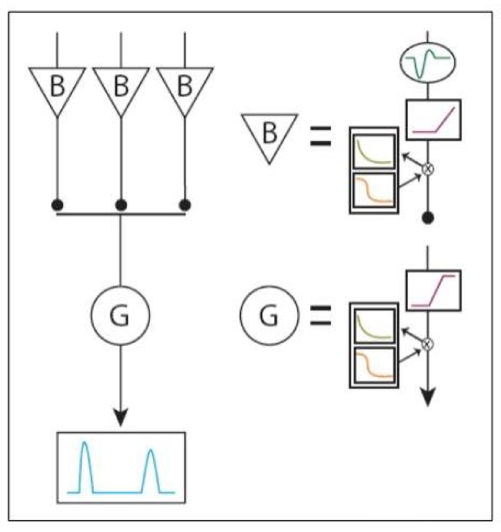
III) Spike frequency adaptation

- Adaptation is commonly defined as a decrease in response to a constant stimulus.
- In our work, we regard it as all the non-linear phenomena involved in the neuronal response to motion stimuli.
- Chen's & al use the following cascade model :

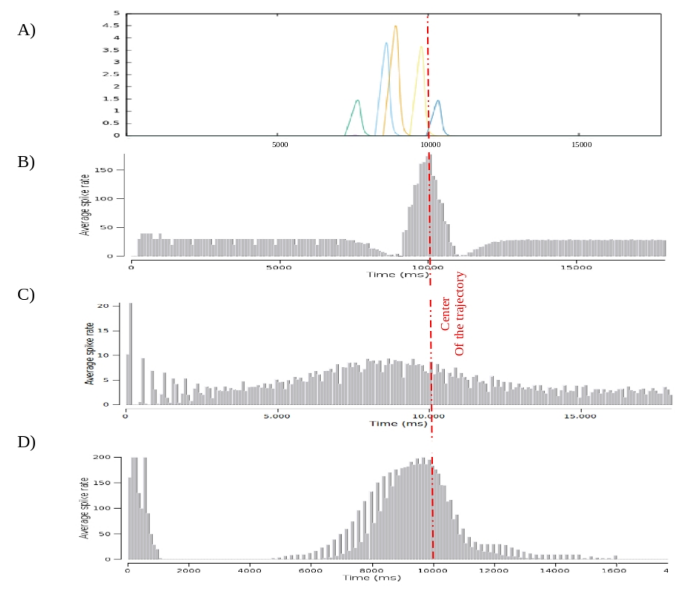


- In order to simulate Chen's & al. gain control mechanism model using pranas, we had to apply a threshold adaptation as a function of the expected output.
- This brought us to investigate other threshold adaptation functions.
- We found that when the threshold is tuned by the fluctuation of the bipolar current, while using a pooling function at the level of RGCs, one can recover motion features introduced earlier.
- More precisely :

$$\theta = \theta_0 - \gamma|\Delta(V_{bip})|$$

IV) Smooth motion results

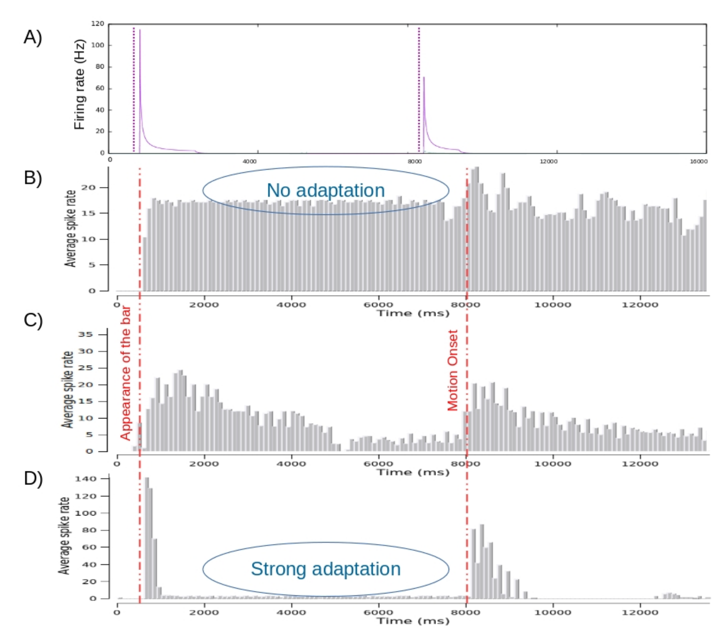
In this section, we show the results of our implementations of the spike frequency adapatation. We recover the anticipatory effect occuring in the case of smooth motion, as the shifted pic of response appears before the bar reaches the center of the receptive field.



Population response to smooth motion of a translating bar A) The results using direct integration of gain control equations. B) The results using linear spatio-temporal filtering at the level of bipolar cells and a discrete leaky integrate and fire model to produce spikes, with PRANAS. C) The results of the implementation of Chen & al. model in PRANAS. D) The results using threshold adaptation as a function of $\Delta(V_{bip})$, and the pooling of bipolar cells by ganglion cells.

V) Alert and motion onset

We also reproduced the alert and the motion onset responses. The motion onset effect appears in the fact that this type of stimulus elicites stronger response than smooth motion, shorter in time. The alert response to the appearance of the bar is higher than the two other motion features.



Population response to alert response and motion onset of a moving bar A),B),C),D) Same as (IV). Spike threshold adaptation seems to perform better in terms of response saliency. The level of alert response is indeed much higher than the motion onset response.

VI) Moving car results

We developed an algorithm to reconstruct the stimulus from the spike trains produced by PRANAS. The following table shows the results of the reconstruction using different models. The hybrid model uses gain control only at the level of bipolar cells and threshold adaptation at the level of ganglion cells. Finally, the connectivity is chosen to be sparse and inhibitory, with a mean of 3 pre synaptic neurons.

Time (ms)	A) Without adaptation	B) Chen & al. Model implementation	C) Threshold adaptation & pooling function	D) Hybrid Model	E)Threshold adaptation with connectivity
T = 500					
T = 1200					
T = 1600					
T = 2100					

Conclusion & future work

- Our treshold adaptation model enabled us to reproduce anticipation, alert response and motion onset.
- The blur occuring in all reconstructions is due to the subunit model (pooling of bipolar cells).
- In terms of run-time efficiency, the threshold adaptation model is more optimal than Chen model.
- Other motion features are still to be investigated, such as motion reversal.
- The role of connectivity is also to be further studied.

References

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